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WATER QUALITY IN FRANK HOLTEN STATE PARK JULY, 1977, THROUGH JUNE, 1984

by

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WATER QUALITY IN FRANK HOLTEN STATE PARK
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Introduction

Frank Holten State Park is a 1,125-acre recreation area in southwestern Illinois, located outside East St. Louis in St. Clair County. The park contains three small lakes whose combined area has been estimated by the Illinois Department of Conservation (IDOC) to be approximately 133 acres, with a combined shoreline of 5 mi. Harding Ditch flows through the park.

Deterioration of lake water quality, primarily through silt deposition and water level fluctuations since their construction in the 1930's, prompted IDOC to develop a restoration plan for the park. In July, 1977, as part of its grant from the U. S. Environmental Protection Agency for lake improvements in Frank Holten State Park, the IDOC included monitoring water quality variables which would reflect the overall effectiveness of the restoration program, which included relocation of Harding Ditch through the park, the construction of an inverted siphon (begun 30 June 1977; completed 28 October 1980), and dredging of the three lakes. Dredging in lakes 1 and 2 began on or about 1 September 1981 and was completed 19 September 1983. Restoration of lake 3 is ongoing. Work began on 1 June 1982 and is continuing. Approximately 3 ft of accumulated sediment was removed from each lake.

Construction work has been completed. To date, approximately 60 collections have been made in the project area from July, 1977, through June 1984. This report summarizes the results of these 7 years of water quality monitoring.

Methods

Station Locations. Five water quality monitoring stations were established, one in each of the three lakes (stations 1, 2, and 3) and two in Harding Ditch (stations 4 and 5). Stream sites were located immediately upstream and downstream of the park. Station locations are illustrated in Figure 1. IDOC personnel collected replicate samples from the five stations beginning in July, 1977; samples have been collected on 60 dates. Dates of sampling are included in Appendix 1.

Field and Laboratory Methods. Field measurements, performed by IDOC personnel, included water temperature (F), dissolved oxygen, free carbon dioxide, hydrogen ion concentration (*p*H), and total alkalinity. Laboratory analyses performed by Illinois Natural History Survey in Urbana personnel on raw water samples are summarized in Table 1.

Table 1

Laboratory Methods for Physical and Chemical Variables
Monitored in the Frank Holten Lake and Harding Ditch Watershed

Variable	Method
EDTA Hardness	EDTA Colorimetric Method (autoanalyzer)
Residue, Total	Constant weight upon drying @ 180 C, unfiltered
Residue, Dissolved	Constant weight upon drying @ 180 C, filtered
Residue, Particulate	By difference
Total Phosphorus	Stannous Chloride Method[1]
Soluble Orthophosphate	Ascorbic Acid Method (autoanalyzer)[1]
Nitrate-Nitrogen	Cadmium Reduction Method (autoanalyzer)[1]
Nitrite-Nitrogen	Diazotization Method (autoanalyzer)
Ammonia-Nitrogen	Berthelot Reaction Method (autoanalyzer)
Organic Nitrogen	Modified Berthelot Reaction Method (autoanalyzer)[1]
Chlorophyll *a*, Phaeophytin *a*	Standard Method[1]

[1] *Standard Methods* (1980).

Most of the analytical procedures used for water analysis in this study are described in detail in the 15th edition of *Standard Methods for the Examination of Water and Wastewater* (American Public Health Association, American Water Works Association, and Water Pollution Control Federation 1980) (*Standard Methods*). Table 1 summarizes the particular method or equipment used for laboratory analysis where more than one was approved and also lists those variables where selected methods were not included in *Standard Methods* or deviated from those methods.

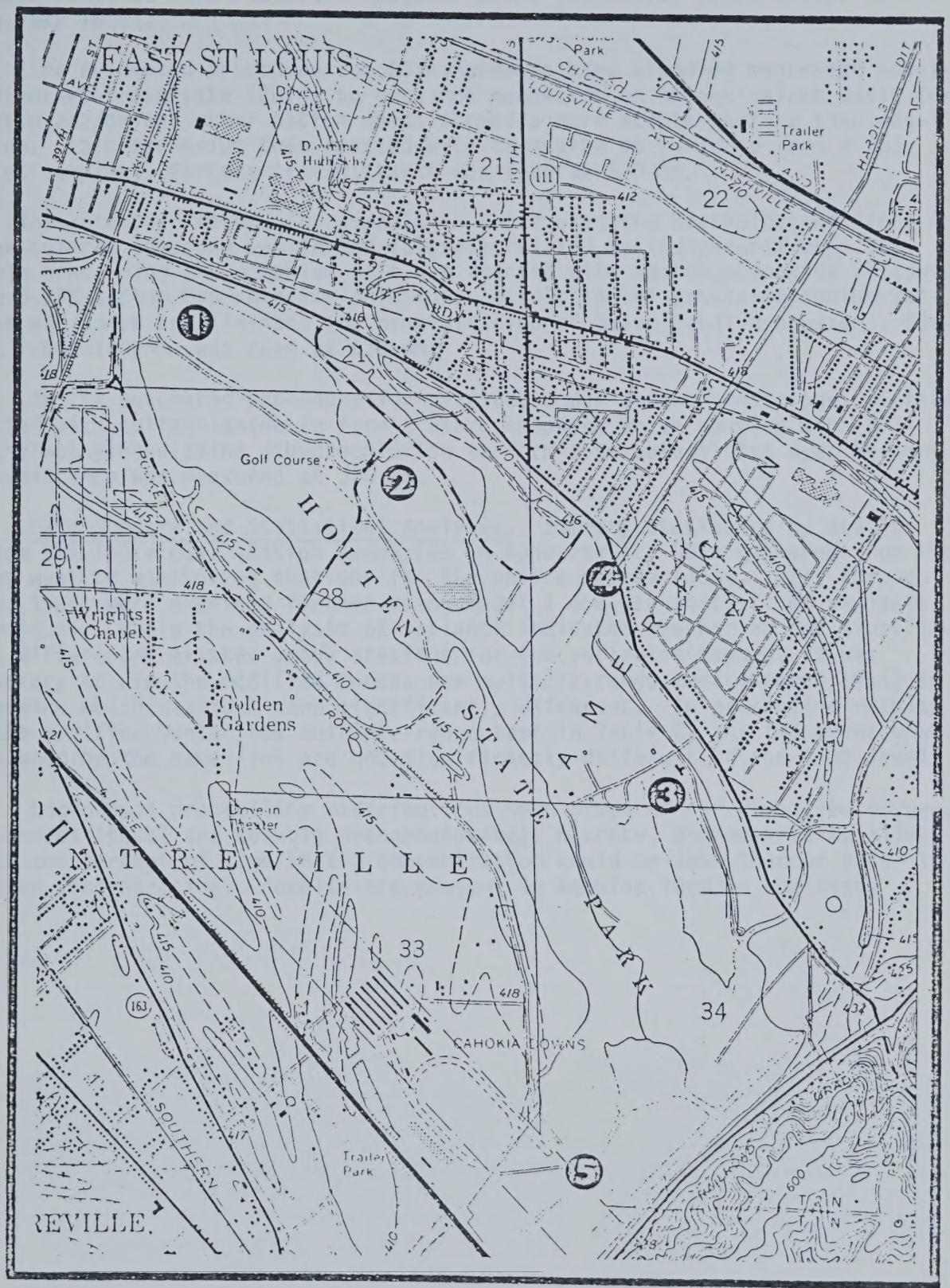

Figure 1. Locations of sampling stations in Frank Holten State Park, St. Clair County, Illinois (French Village 7.5-min. quadrangle map, 1954 ed., photorevised in 1968 and 1974).

The procedural modifications for EDTA hardness, ammonia, and nitrite methods resulted from the use of autoanalyzers (Technicon Corporation, Tarrytown, New York).

The automated procedure for EDTA hardness used disodium magnesium ethylenediaminetetraacetate (EDTA) to exchange magnesium on an equivalent basis for calcium and/or any other cation which formed a more stable chelate than magnesium. This magnesium then reacted with calmagite at *p*H 10 to form a red-violet complex. Percent transmittance was read at 520 nm.

The automated method for ammonia in water used the Berthelot reaction. A green-colored compound was formed (closely related to indophenol) when the sample containing the ammonium salt was reacted with sodium phenoxide followed by a 5.25% sodium hypochlorite solution. A solution of potassium-sodium tartrate was added to eliminate the precipitation of heavy metal hydroxides. Percent transmittance was read at 630 nm.

In the automated procedure for nitrite, under acidic conditions, nitrite reacted with sulfanilamide to form a diazo compound which coupled with N-1-napthyl-ethylenediamine dihydrochloride to form a soluble violet dye. Percent transmittance was measured at 520 nm.

Data Summary and Statistical Analyses. Summary statistics by station follow the individual station summaries in Appendix 1. Data gathered from the water quality monitoring stations for the entire period (July, 1977, through June, 1984) were examined further using Model I one-way analysis of variance techniques. While the analysis of variance indicated whether or not significant differences existed among stations for the variables tested, it was necessary to use the modified Duncan new multiple-range test (Kramer 1956) to determine which stations were significantly different. In presenting results of the modified Duncan new multiple-range test in Table 2, any two means underscored by the same line are not significantly different at the 0.05 level.

Log-normal probability distributions were prepared for dissolved oxygen, phosphorus (total and soluble orthophosphate), nitrate, and ammonia to illustrate the percent of time that a concentration could be less than or equal to a given concentration. Results are present in tabular form in the text.

General Limnological Features

The concentrations observed at sampling sites in the Frank Holten Lake and Harding Ditch watershed were unremarkable in that they were consistent with concentrations observed at other sites in Illinois by being neither unusually high or low. In fact, water quality appeared to be better than might be expected in a primarily urban watershed.

The viscosity and density of water and also the solubility of gases, especially oxygen, in water are functions of water temperature. As the medium for aquatic organisms, water and its temperature are important. Aquatic species have lower and upper thermal tolerance limits, optimum growth temperatures, preferred temperatures in thermal gradients, and temperature limitations for reproduction, migration, and egg incubation (Committee on Water Quality Criteria 1972). The annual water temperature regime in the project area consisted of four broad categories: a summer high (June, July, August), an autumn transition period (September, October, November), a winter low (December, January, February), and a spring transition period (March, April, May). Lake and stream water temperatures were virtually identical on most sampling dates.

Apart from its importance in sustaining aquatic life, the presence of dissolved oxygen serves as an indicator that excessive oxygen-demanding substances are not present. It is therefore desirable for oxygen to be present in water at or near saturation. The range of dissolved oxygen observed over 7 years was broad. As the solubility of oxygen is inversely related to water temperature, concentrations were generally highest during winter and lowest during summer. Concentrations of dissolved oxygen were frequently lower in Harding Ditch than in the lakes, often exhibiting a difference of over 1 mg/l. This is not unusual when comparing autotrophic systems such as lakes to heterotrophic systems such as streams. In streams the principal source of oxygen throughout the year is atmospheric reaeration; the contribution from primary production is small by comparison to that in lakes.

The complex interactions between carbon dioxide, bicarbonate and carbonate ions, and hydrogen ion concentrations (*p*H) can be broadly summarized as waters with greater alkalinities are least subject to extreme variations in *p*H because of the buffering capacity, or the ability of the system to absorb carbon dioxide. Since the toxicity of most pollutants can be a function of *p*H and the tolerance of aquatic organisms to low dissolved oxygen, high temperature, cations, and anions also varies as a function of *p*H, the hydrogen ion concentration, expressed as *p*H, is a very important variable.

Levels of hydrogen ion concentration (*p*H) were more variable in the lakes than in Harding Ditch. Two factors contributed to the results observed: the importance of primary production in the lakes and that the lakes were weakly buffered compared to Harding Ditch. As discussed below, p*H* may be high in the lakes in summer during the day as a result of increased algal and/or aquatic macrophytic primary production. This can also occur in winter, especially under clear ice following several days of bright, clear weather, from planktonic photosynthesis.

Briefly, during photosynthesis, the uptake of carbon dioxide causes the *p*H to increase as the equilibrium shifts in the carbonic acid/bicarbonate/car-

bonate reactions as carbon dioxide concentrations decrease. The impact of primary production upon the bicarbonate concentrations can be seen in the lowest concentrations of bicarbonate (and, to a lesser degree, carbonate above *p*H 8.3) generally occur during summer and early autumn, corresponding to periods of peak productivity. Since streams are primarily heterotrophic systems, not only is primary production lower in Harding Ditch, but the system is well-buffered (total alkalinity often twice that observed at lake sites). EDTA hardness as a measure of the cationic component (calcium and magnesium compared to the anionic or bicarbonate/carbonate fraction of total alkalinity) reflected this same phenomenon.

Concentrations of free carbon dioxide were commonly higher in Harding Ditch than in the lakes. Concentrations of free carbon dioxide are often highest in autumn when the decomposition of allochthonous materials derived from leaf fall or autochthonous materials such as decaying aquatic macrophytes or phytoplankton exerts a high oxygen demand. Concentrations are also frequently elevated during periods of high surface runoff which washes sediment or other particulates into the water.

While one would expect the free carbon dioxide concentrations in the lakes to be low as a function of its importance in photosynthesis, an additional contribution to higher concentrations in Harding Ditch would be from East St. Louis, a likely source of oxygen-demanding substances. While elevated carbon dioxide levels can interfere with respiration in fish thus affecting oxygen uptake, most species of fish can extract dissolved oxygen from water below 60 mg/l of free carbon dioxide (Committee on Water Quality Criteria 1972). Concentrations of the magnitude to affect fish were not observed during the period monitored.

Residues (total, dissolved, particulate) were variable. Fluctuations in total residue paralleled changes in the dissolved fraction. While particulate residue was occasionally high, it was not often a significant contribution to the total residue observed. Concentrations of all forms of residue were significantly higher in Harding Ditch than in the lakes, generally at least two times the magnitude of the lake concentrations. Although reducing turbidity in the lakes is one of the goals of the restoration project, it is apparent that at least by weight, the suspended matter in the lakes is not significant. Its impact upon light penetration or feeding by sight-feeding fish cannot be assessed.

Concentrations over the annual cycle varied, with the highest concentrations of residues observed during winter, and to a lesser degree, spring. Lowest concentrations were observed during summer and autumn. Dissolved and particulate materials would be contributed during periods of heavy rainfall and high surface runoff, common in spring and winter (from rain and/or snow melt, especially if salt is used for ice control).

Major sources of phosphorus to fresh water include runoff from surrounding agricultural land and municipal wastewater effluents. The source of phosphorus can frequently be determined by considering its form in water. Total phosphorus is derived chiefly from the particulate matter in water and often reflects an agricultural source. Thus, total phosphorus concentrations are generally positively correlated with turbidity.

Concentrations of phosphorus, both total and soluble orthophosphate, were lower in the lakes than in Harding Ditch. In both habitats, however, phosphorus concentrations followed a cycle in which the highest concentrations were observed during spring and summer than in autumn and winter.

In natural surface waters, nitrogen usually occurs most frequently in its oxidized form, nitrate. Since nitrogen is readily leached from soil, nitrate concentrations are often highest in spring following flooding or heavy rains. In the lakes, nitrate concentrations rarely exceeded detection limits and only occasionally exceeded 0.1 mg/l. In contrast, concentrations in Harding Ditch were high and variable. Similarly, nitrite was rarely above detection limits in the lakes, but in Harding Ditch its concentrations paralleled those of nitrate, increasing and decreasing as did nitrate.

In contrast, organic nitrogen and often ammonia concentrations were higher in the lakes than in Harding Ditch, serving as the principal nitrogen form in the lakes. Organic nitrogen concentrations were highest in the lakes during the lake summer and early autumn, probably coincident with the beginning declines in phytoplankton and aquatic macrophytes. Ammonia concentrations were quite variable, exhibiting no consistent trends.

Phytoplankton is a variable component in lakes, its species composition and abundance changing rapidly within a short time. While biological sampling was not within the scope of the monitoring program, phytopigment analyses were performed to reflect the relative standing crop of phytoplankton in the lakes and Harding Ditch. Concentrations of chlorophyll *a* and phaeophytin *a* were higher at lake sites than in Harding Ditch. Concentrations in the lakes peaked during summer, with the highest concentrations occurring from spring through autumn. Smaller peaks occurred in Harding Ditch at these same times.

Relationships Among Stations

Results of analysis of variance and multiple-range testing are presented in Table 2. All references to significance are at the 0.05 level. This analysis was performed on data for the period July, 1977, through June, 1984. Of 17 variables examined by these techniques, only water temperature showed no significant differences among stations. These surface values reflect the reasonably short time span on each date that sampling at all stations occurred. This lack of difference among surface sampling sites is not unusual.

There were significant differences in concentrations observed among other variables which could be attributed to the basic limnological differences between lake and stream habitats. Variables for which either the lake or Harding Ditch sites were significantly different from one another included total alkalinity, EDTA hardness, free carbon dioxide, nitrate, nitrite, organic nitrogen, residue (total, dissolved, particulate), and phaeophytin *a* (Table 2).

EDTA hardness showed a progressive increase among all stations from lake sites through stream sites. Lake sites 1 and 2 were not significantly different from one another, nor were the Harding Ditch sites. Lake 3, significantly different from both groups, occupied an intermediate position. Total alkalinity concentrations also increased progressively from lake 1 to the stream sites; the Harding Ditch sites, however, were not statistically distinct. Total alkalinity was an estimate, in this case, principally of bicarbonate ion (the anionic fraction) while EDTA hardness was an estimate of calcium and magnesium (the cationic fraction), both variables expressed as calcium carbonate.

Free carbon dioxide also followed this general pattern of increasing concentration from lake to stream. Concentrations in Harding Ditch were significantly higher than those recorded for the lake sites. In general, hydrogen ion concentration (*p*H) was also significantly higher at lake sites than in Harding Ditch, attributable in part to primary production in the lakes. Correspondingly, both total alkalinity and EDTA hardness were significantly higher in the stream than in any of the lakes.

Nitrate is highly soluble and concentrations commonly increase during periods of heavy rainfall and surface runoff. Concentrations of nitrate were significantly lower in the lakes than in Harding Ditch. As the ditch has a larger watershed than any of the lakes and flows through East St. Louis before entering the park, nitrate concentrations would be expected to be higher. In addition, phytoplankton and aquatic macrophytes in the lakes serve as effective nutrient traps, utilizing much of the available nitrogen. Nitrite concentrations, as an intermediate oxidative state of nitrate, followed those of nitrate, but at much lower concentrations. The log-normal probability distribution for nitrate summarized below illustrates the typically low concentrations observed in the watershed.

Organic nitrogen concentrations, however, were not only higher in the lakes, but significantly so. Mean concentrations in the lakes were several times higher than those observed in Harding Ditch. Usually nitrate is the principal nitrogen form in water. That organic nitrogen would predominate in the lakes suggests one reason for the generally low dissolved oxygen profiles recorded by IDOC personnel on field records. Organic nitrogen is unstabilized, requiring oxygen for its oxidation and stabilization as nitrate.

Table 2

Relationships Among Mean Concentrations
of Physical and Chemical Variables
at Stations in the Harding Ditch Watershed
(July, 1977, through June, 1984)

Variable[1,2]	n	Station 1	2	3	4	5
Water Temperature (F)	282	62.50	63.39	63.54	60.74	61.11
Hydrogen Ion Conc. (*p*H)	290	8.42	8.39	8.10	7.93	7.63
Free Carbon Dioxide	167	2.8	1.9	5.3	7.3	11.3
Total Alkalinity (as $CaCO_3$)	441	95.0	117.8	155.4	231.3	242.3
EDTA Hardness (as $CaCO_3$)	592	103.3	132.9	234.5	347.1	382.9
Nitrate (as N)	592	0.066	0.055	0.067	0.886	0.604
Nitrite (as N)	592	0.013	0.011	0.022	0.092	0.060
Organic Nitrogen (as N)	592	1.385	0.988	1.235	0.420	0.432
Total Residue @ 180 C	592	230.8	246.6	387.4	614.7	651.5
Dissolved Residue @ 180 C	591	204.5	224.9	340.9	535.6	569.9
Particulate Residue @ 180 C	591	26.2	21.7	46.5	96.1	80.3
Phaeophytin *a*	585	15.88	10.83	22.84	3.77	6.23
Ammonia (as N)	592	2 0.293	5 0.309	4 0.366	1 0.446	3 0.498
Chlorophyll *a*	584	1 84.47	3 94.01	2 55.73	4 11.28	5 14.45
Dissolved Oxygen (surface)	283	1 9.00	2 8.81	4 9.30	3 8.18	5 7.87
Total Phosphorus (as P)	592	1 0.174	2 0.130	3 0.256	5 0.271	4 0.436
Soluble Orthophosphate (as P)	592	0.053	0.039	0.079	0.079	0.217

[1]Expressed as mg/l unless other units are indicated.

[2]Any two means underscored by the same line are not significantly different by the modified new Duncan multiple-range test (0.05 level).

Station	Log-Normal Probability Distribution for Nitrate (mg/l N)					
	5%	10%	25%	50%	75%	95%
1	--	--	--	0.03	0.05	0.20
2	--	--	--	0.03	0.05	0.14
3	--	--	--	0.03	0.06	0.30
4	0.01	0.05	0.35	0.80	1.15	2.00
5	0.01	0.05	0.14	0.50	0.90	1.00

The forms of residue exhibited significant differences between lake and stream sites, with lake 3 (station 3) occupying an intermediate position between lakes 1 (station 1) and 2 (station 2) and the Harding Ditch sites. Total residue was significantly different among all stations, increasing progressively from lake to stream sites. Dissolved residue followed a similar pattern to that observed for total residue. Dissolved residue is the major portion of the total residue and reflects primarily concentrations of EDTA hardness (an estimate of calcium and magnesium concentrations expressed as calcium carbonate) and total alkalinity (an estimate of bicarbonate concentrations expressed as calcium carbonate). However, the contrast between the two major habitat types (lake versus stream) was more pronounced as neither the lakes nor the stream sites were statistically distinct from each other.

Particulate residue was significantly higher in Harding Ditch. This is not unexpected as water velocity in the channel would maintain silt and other particules in suspension. The lake basins allow sedimentation to occur; consequently, concentrations of particulate residue are significantly lower.

Phytopigment concentrations were significantly higher in the lakes (stations 1 through 3) than in Harding Ditch (stations 4 and 5). Concentrations of both chlorophyll *a* and phaeophytin *a*, its degradation product, were several times greater in the standing-water habitats, as would be expected. As autotrophic systems, lakes develop both phytoplankton and periphyton communities. Periphytic species develop especially diverse populations when aquatic macrophytes are available for colonization. As heterotrophic systems, however, streams do not develop a true phytoplankton community. Instead, periphyton develops on available substrates, such as rocks, logs, mud, or sand. As this periphytic growth continues, portions continuously slough off and are swept into the water column, creating a depauperate "phytoplankton".

Relationships observed among the remaining variables were not as clearly defined as those described above. The lake sites generally had lower phosphorus concentrations than stream sites. Lake 3 again occupied an intermediate position. It is likely that the shallow basin of lake 3 enabled circulation more or less continuously, rather than limited to spring and autumn overturn periods, and maintained particulate matter in suspension. For phosphorus, lake 3 more closely resembled sampling stations in Harding Ditch and, in fact, was statistically indistinguishable from station 5 in the ditch.

The relationships among stations observed for ammonia were not clearly defined. Lake sites did not have lower concentrations than those observed in the stream, as one might expect.

Comparison to the Illinois Water Quality Standards

The intention of the general water quality standards is to protect Illinois water for aquatic life, primary and secondary contact use, and to ensure the aesthetic quality of the aquatic environment. Most Illinois waters should meet these general standards. Four variables measured in this study are among those chemical constituents listed in the general standards: dissolved oxygen, hydrogen ion concentration (*p*H), phosphorus, and ammonia. By comparing the results obtained in the present monitoring program to the appropriate general water quality standards, existing water quality can be generally evaluated.

Low dissolved oxygen concentrations are the most serious water quality problem in the project area to be solved. The causes are complex; combinations of turbidity limiting oxygen production, oxygen-demanding substances in the lakes, and biological respiration. Removal of 3 ft of accumulated sediment from each of the lakes, however, should improve dissolved oxygen concentrations by limiting the amount of potential oxygen-demanding material in the sediment.

Dissolved oxygen concentrations are expected to be at least 6 mg/l for at least 16 hr of any 24-hr period with concentrations never falling below 5 mg/l. Dissolved oxygen profiles taken by IDOC personnel illustrate that concentrations were often at or below the 5 mg/l level during the day when concentrations would be expected to be highest as a result of photosynthetic activty.

Log-normal probability distributions for dissolved oxygen, summarized below, illustrate the percent of time that a concentration less than or equal to that presented in the table would be observed. The percentages below are based upon dissolved oxygen profiles recorded from the three lakes in Frank Holten State Park from July, 1977, through June, 1984.

In lakes 1 and 2, 10 percent or fewer of the surface dissolved oxygen concentrations would be expected to fall below the 5.0-mg/l standard; 20 percent or fewer below 6.0 mg/l. Bottom concentrations were much lower, as might be expected. Approximately 60 to 65 percent of all concentrations would be below 5.0 amd 6.0 mg/l.

Station	Log-Normal Probability Distribution for Dissolved Oxygen (mg/l)	
	5.0	6.0
1 (S)	8%	20%
1 (M)	35%	53%
1 (B)	58%	65%
2 (S)	10%	19%
2 (M)	48%	53%
2 (B)	60%	62%
3 (S)	18%	23%

After 31 December 1983, phosphorus as P shall not exceed 0.05 mg/l in any stream at the point where it enters any reservoir or lake with a surface area of 20 acres or more. Virtually all concentrations of total phosphorus at all sites exceed this general standard. Most concentrations of soluble orthophosphate were greater than or equal to 0.05 mg/l P in Harding Ditch. Soluble orthophosphate concentrations were lower in the three lakes, exceeding 0.05 mg/l P less frequently. At station 3, however, in lake 3, concentrations in excess of 0.05 mg/l were more common.

Station	Log-Normal Probability Distribution for Total Phosphorus (mg/l P)					
	5%	10%	25%	50%	75%	95%
1	0.06	0.08	0.11	0.15	0.21	0.30
2	0.06	0.07	0.08	0.12	0.16	0.20
3	0.06	0.07	0.11	0.21	0.35	0.65
4	0.17	0.19	0.27	0.38	0.52	1.3
5	0.11	0.14	0.19	0.25	0.31	0.60

Station	Log-Normal Probability Distribution for Soluble Orthophosphate (mg/l P)					
	5%	10%	25%	50%	75%	95%
1	--	--	0.02	0.04	0.08	0.15
2	--	--	0.02	0.03	0.04	0.08
3	--	0.01	0.02	0.06	0.10	0.17
4	0.02	0.03	0.06	0.14	0.27	0.55
5	--	0.01	0.03	0.05	0.08	0.20

In the absence of any wastewater source, phosphorus enters a surface water primarily in particulate form, adsorbed onto the surfaces of soil particles. Once in suspension, the phosphorus may go into solution or it may settle out only to be resuspended during the next high-water period. The combined action of biological activity and sedimentation frequently reduces the concentrations observed in lakes (as here), but stream flow generally settle out only to be resuspended during the next high-water period. Any watershed plan which limits surface erosion will help to reduce the phosphorus concentrations observed in the project area.

Although the range of *p*H in the general water quality standards is 6.5 to 9, values outside this range are acceptable if they are naturally occurring. Several values over 9 were observed in the three lakes, primarily during summer (Appendix 1). Values may be high in summer during the day as a result of increased algal and/or aquatic macrophyte production. This can also occur in winter, expecially under clear ice following several days of bright, clear

weather, from planktonic photosynthesis. Briefly, during photosynthesis, the uptake of carbon dioxide causes the *p*H to increase as the equilibrium shifts in the carbonic acid-bicarbonate-carbonate reactions as carbon dioxide concentrations decrease.

Several concentrations of ammonia observed at stations 1, 3, 4, and 5 exceeded the 1.5 mg/l maximum concentration of the general standards. These were isolated incidents and were likely the result of localized conditions since there were not comparably high concentrations at other sites or on other dates. Mean concentrations at all stations are well below 1.5 mg/l.

	Log-Normal Probability Distribution for Ammonia (mg/l N)					
Station	5%	10%	25%	50%	75%	95%
1	--	--	0.21	0.38	0.62	0.98
2	--	--	0.15	0.29	0.38	0.60
3	--	--	0.25	0.34	0.66	1.00
4	--	--	0.13	0.23	0.40	1.00
5	--	--	0.15	0.26	0.38	0.80

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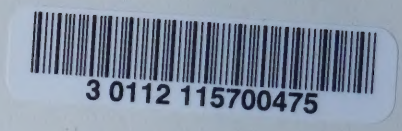
APPENDIX 1

Water Quality Summaries
July, 1977, through June, 1984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